The 30-second Time-of-Flight Exam: Improving Image Quality with Modern Acceleration Methods

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Introduction: Acute ischemic stroke is a leading cause of permanent disability and death in North America. Prompt diagnosis is vital to initiate timely intervention and minimize irreversible brain damage. Currently, computed tomography (CT) is the standard of care for patients presenting with acute ischemic stroke; with improved rapid imaging methods, MR imaging may supplant CT for acute stoke assessment. Rapid time-of-flight (TOF) angiography will be central to this transition. Currently, conventional high-resolution TOF protocols routinely exceed 4–5 minutes; shorter protocols sacrifice spatial resolution and/or volume coverage. Clinical scanners provide acceleration rates between 2× and 4× via parallel imaging, but images are subject to noise amplification and residual aliasing artifacts. Advanced sampling schemes and constrained reconstruction may provide drastic improvements to image quality. In this work, we investigate TOF image quality using auto-calibrated parallel imaging and compressed sensing in a highly time constrained environment: allowing only 30 seconds per slab. We hypothesize that the improved resolution available via accelerated TOF approaches will provide more details of cerebral vasculature compared to the fully sampled approach collected over the same time interval and, with modest to high acceleration rates, will outweigh the artifacts and additional noise associated with undersampling.

Methods: One fully sampled and five prospectively undersampled data sets, ranging from 2× to 6× acceleration, were acquired using an axial 3D SPGR sequence. The data was obtained from healthy volunteers using a 3 T scanner (GE Discovery MR750) and a 32-channel receive-only head coil. For all data sets, we used the same acquisition time of 30 s, TR of 22 ms, flip angle of 15º, bandwidth of 25 kHz, and FOV of 22 × 22 × 3.0 cm^3. Acceleration was employed to increase the acquisition matrix from 256 × 114 × 12 (fully sampled) up 256 × 240 × 34 (6× acceleration). Accelerated data were acquired with variable density Poisson disk sampling schemes [1] and reconstructed offline using the sparse SENSE model:[1,2]

$$\arg\min_{\mathbf{m}} \ \|\mathbf{Em}-\mathbf{y}\|_2^2 + \lambda_1\|\boldsymbol{\Psi}\mathbf{m}\|_1 + \lambda_2\|\mathbf{Tm}\|_1$$

where **E** is the sensitivity encoding matrix, **m** is the 3D image to reconstruct, **y** is the acquired k-space data, Ψ is a 3D wavelet transform, and **T** is the total variation. Sensitivity maps were computed using the eigenvector decomposition method proposed in [3]. Accelerated images were qualitatively compared to the fully sampled case based on vessel conspicuity, noise, and reconstruction artifact. Line profiles through a region with several small vessels were obtained and compared based on effective resolution and contrast.

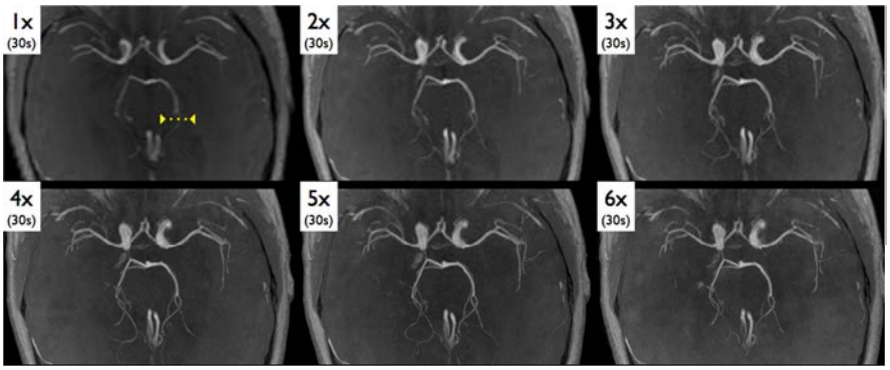

Figure 1: TOF images reconstructed from prospectively undersampled data. The acceleration factor increased from 1× (fully sampled) to 6×, while maintaining a 30s acquisition time.

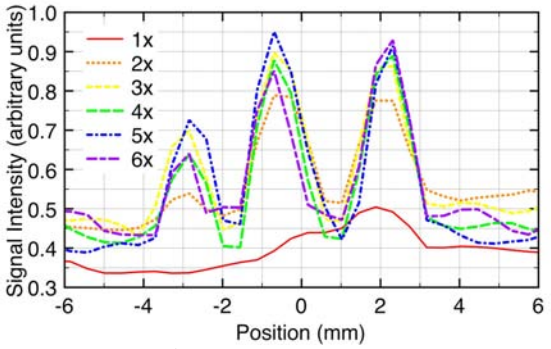

Figure 2: Line profiles through the region indicated in Fig. 1. Arterial conspicuity increases with acceleration rate up to approximately 5×, above which residual aliasing artifacts and smoothing from the ℓ_1 reconstruction penalties begin to excessively obscure small vessels.

Results: Fig 1 shows maximum-intensity projection (MIP) images from the fully sampled case (1×) and the accelerated cases (2×–6×), each acquired over 30s. Vessel–to–tissue contrast was superior in all accelerated cases relative to the fully sampled case. Visually, vessel conspicuity increased with acceleration factor, peaking at 5×. At 6×, residual aliasing and compression artifacts from the constrained reconstruction obstruct small vascular features. These observations are supported by line profiles (Fig. 2) where the 5× acceleration provides the best combination of resolution and contrast. Sparse SENSE reconstruction time for the 4× data set was 102 seconds.

Discussions: In a very time-limited exam, diagnostic quality TOF images can be obtained via data undersampling and modern non-linear reconstruction methods. Here, acceleration is employed to increase spatial resolution, and thus potentially resolve smaller arteries. The constrained reconstruction mitigates the SNR reduction typically associated with higher resolutions, but compression and aliasing artifacts may obscure subtle features and reduce the effective image resolution (based on vascular discrimination). We observed that an acceleration rate of 5× optimally balanced voxel size and the ability to distinguish small vessels. This result suggests that acceleration rates beyond those available commercially are clinically beneficial and enable high quality TOF imaging, with potential application in the acute stroke environment. Although current reconstruction times were ~3.5 times longer than the acquisition time, optimized reconstruction is anticipated to provide near-instantaneous image reconstruction. We believe this approach will eventually contribute to a shift toward MR in the standard-of-care for acute stroke imaging.

References: [1] Lebel RM, *et al.* ISMRM 20 2012; 10. [2] Liu B, *et al. ITAB* 2008; 127. [3] Lai P, *et al.* Proc Intl Soc Mag Reson Med 18 2010; 345.